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Operational Research on Microphone and Studio Techniques in Stereophony

by

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(Research Department, BBC Engineering Division)

BRITISH BROADCASTING CORPORATION

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FOREWORD

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This series should be of interest and value to engineers engaged in the fields of broadcasting and of telecommunications generally.

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OPERATIONAL RESEARCH ON MICROPHONE AND STUDIO TECHNIQUES IN STEREOPHONY

SUMMARY

In order to gain practical experience in stereophony as applied to broadcast programmes, a series of operational experiments has been carried out by the BBC Research Department, in collaboration with Operations and Maintenance Department and the programme departments. The conclusions to be drawn from the experiments are discussed with particular reference to the problem of securing compatibility in transmission and to the design and operating requirements of the special studio equipment necessary.

Sufficient experience has been gained to serve as a basis for the detailed planning of future stereophonic studios, control equipment, and programmes.

1. Introduction

During 1957 considerable interest in domestic stereophonic reproduction was stimulated by the introduction of commercial stereophonic tape recordings on the home market and by the prospect of stereophonic disc recordings becoming available in the immediate future. The decision was therefore taken in November of that year to start investigating the technical problems which would arise in the application of stereophony to broadcasting. The first results of this investigation, which included consideration of the various systems of radio transmission and of the special requirements to be met by the land lines between studios and transmitters, were given in a monograph[1] published in April 1960. The present monograph is concerned with the production of stereophonic broadcast programme material by appropriate microphone and studio techniques; the methods employed, while not differing in principle from those adopted in commercial gramophone recording studios, involve some special problems by reason of the wide variety of items to be covered, the importance of compatibility,* and the need for 'live' as well as recorded programmes.

The principal object of the investigation to be described was to consider the application of stereophony to various types of programme material and the technical problems peculiar to each. As a by-product of the project, it was also desired to obtain material for experimental broadcasts and, at a later stage, for an international study of stereophonic techniques organized by the European Broadcasting Union (E.B.U.). The various aspects of the investigation may be classified as follows:

1. Microphones and methods of using them.
2. The degree of compatibility obtainable, i.e. the extent to which a stereophonic transmission could be made to yield an acceptable monophonic programme.
3. Any special technical requirements in the design of studios and control equipment.

Early tests were restricted to existing rehearsals or transmissions, but it soon became apparent that the investigation could not be further pursued without a series of special sessions with performers engaged for the purpose; this was eventually arranged and a series of operational experiments, covering a variety of programme material, was commenced. The present monograph deals with the progress of the investigation up to May 1960.

It is not the purpose of this monograph to give a detailed chronological account of all the operational experiments,† but rather to summarize and discuss the results obtained under the headings given above, amplifying in the process those conclusions already given in the earlier publication.[1]

2. Microphones

2.1 *General*

When the investigation was commenced, the microphone arrangements already used or proposed for two-channel stereophonic transmission could be summarized as follows:

(*a*) A pair of spaced omnidirectional microphones, supplemented in some cases by a third microphone, centrally placed, the output of which was divided equally between the left- and right-hand channels. The stereophonic effects produced were primarily due to interchannel time differences although, in cases where the distance of the source from the microphone was comparable with the microphone spacing, interchannel amplitude differences‡ also played some part.

(*b*) A variant on (*a*) in which the two microphones were placed on either side of a small baffle, or set in either side of a dummy head, the shadowing effect of which produced interchannel amplitude differences at high frequencies.

(*c*) A pair of identical directional microphones, mounted coincidently, i.e. so close together that differences in the times of arrival of a given sound were negligible,

* Definitions of this and other special terms used in stereophony are given in Reference 1.

† The principal experimental sessions are listed in Appendix I.

‡ It is important to avoid confusion between *interchannel* and *interaural* differences. Only with headphone listening do these quantities become identical.

and inclined to left and right. The stereophonic effects depended solely on interchannel amplitude differences.

(*d*) A variant on (*c*), employing a microphone having a figure-of-eight polar diagram facing left and right, combined with a forward-pointing cardioid or omnidirectional microphone. The left- and right-hand signals were derived respectively by adding and subtracting the two microphone outputs. This microphone arrangement is often known as the M–S system; it is usually attributed to Lauridsen[2] but was in fact covered by the classical Blumlein[3] patent of 1931.

(*e*) A combination of (*a*) and (*c*), employing two or three spaced directional microphones, the stereophonic effects being produced by a combination of time and amplitude differences between channels.

In the course of the early experiments, each of the above techniques was employed at one time or another, but it was not practicable, in the limited time then available during rehearsals, to compare all of them on any one occasion, still less to explore for each system every possible combination of microphone spacing and directional characteristic. It soon became clear, however, that while all these arrangements were capable of producing effects much superior to any obtainable with monophonic reproduction, the images produced by spaced omnidirectional microphones were less sharply defined than those obtained with coincident directional microphones, while with the dummy head, which has little directional effect at low frequencies, a large part of the reverberant sound was confined to the centre of the stage. It was therefore decided to concentrate primarily on the possibilities of coincident microphone pairs, using spaced microphones only when forced to do so.

Electrostatic microphones were used for all except a few outdoor experiments, since only with this type* is it possible to obtain a readily adjustable polar characteristic which is substantially independent of frequency. The most generally useful microphones were found to be the A.K.G.† C12 and the more recent model C24, which contains two C12 capsules mounted one above the other in a common housing. When using C12 microphones as a coincident pair the two were placed side by side with their cases in contact, rather than one above the other end to end, to avoid the double obstacle effect which would result from having a pre-amplifier both above and below the capsules. It should be noted that, when using microphones placed one above the other, the effect of the finite distance between them is to introduce time differences for sound sources lying above or below the mean axis. These time differences, if large enough, produce the effect of sideways displacement of the reproduced image so that, for example, an actor's voice and the sound of his footsteps may appear to come from different points on the stage;‡ such effects were noticed during early tests. While no difficulty of this kind has so far been encountered with the C24 microphone, in which the capsules are mounted one above the other with a spacing of 3·8 cm, it would appear that, in any instance where the distance between nominally coincident microphones cannot be made negligibly small, side-by-side mounting is the lesser of the two evils.

* It should be noted, however, that not all electrostatic microphones meet these requirements. For example, one type of variable directivity microphone, which was employed in many of the experiments, could be used only with a figure-of-eight polar characteristic, since the nominal cardioid characteristic was not maintained at low frequencies.

† Akustische und Kino-Geräte Gesellschaft.

‡ Definitions of this and other special terms used in stereophony are given in Reference 1.

2.2 *Single Coincident Microphone Pair*

The earliest experiments employing a single coincident microphone pair were carried out in a large orchestral studio (Maida Vale 1) and in the Royal Albert Hall; in addition to works for orchestra alone, concertos for piano and for violin were being performed and it was found possible in each case to obtain a satisfactory balance without recourse to a separate microphone for the soloist.

In these and later orchestral recording experiments an unexpected difficulty arose. Although the positions of the various instruments in the horizontal plane were faithfully reproduced, observers would complain that the reproduction was biased too far to the right, or to the left, or was confined to a narrow region in the centre of the stage. Clearly, in the absence of vision, the 'acoustic centre of gravity' of the orchestra is decided by the particular instruments which at any one time are contributing most to the total sound. Artificial compensatory bias, obtained by altering the relative gains of the left- and right-hand channels, was attempted, but this expedient is limited in its scope by the fact that the reverberant sound, which forms, as it were, a frame for the stereophonic picture, is likewise displaced. Electrical adjustment of the scale of width can be used to correct an unduly narrow presentation but, for reasons to be explained later, this artifice increases the apparent reverberation and so gives the effect of a more distant pickup. Thus, to obtain an aesthetically satisfactory distribution of sound images across the stereophonic stage, some degree of grouping of the performers according to the type of music being played may be desirable. Similar considerations were later found to apply to light music, Latin American music, and dance music.

Contrary to expectation, the optimum microphone distance for the stereophonic microphone was found to be no greater than that for the corresponding monophonic microphone, and indeed in some cases a closer position was preferred. Possible reasons for this are discussed later in relation to the subject of compatibility.

For the sake of completeness it should be added that wherever artificial reverberation was introduced a stereophonic microphone pair was employed in the 'echo' room. In most of the experiments, two BBC type PGS[4] microphones, which have a figure-of-eight polar characteristic, were set about 15 cm apart in the horizontal plane and with their axes at right angles. The disadvantages normally associated with spaced microphones do not apply to the diffused images produced by an echo room provided that

the spacing is not so wide that the two signals are virtually uncorrelated.

2.3 *Multi-microphone Techniques*

The need for a multi-microphone arrangement was first encountered in experiments with the BBC Revue and Variety Orchestras at the Aeolian Hall. At the start of the session an attempt was made to employ an orchestral layout approximating to the normal for this type of music, but it immediately became apparent that drastic changes were necessary to give good balance combined with a reasonable distribution of instruments across the stage. Eventually, a series of very successful stereophonic recordings was obtained by regrouping the players as required between items.

Orchestras of the Revue and Variety type are not normally balanced as a whole from the point of view of a listener in the studio, and the music is arranged on the assumption of a system of close microphones, by which the balance can be directly regulated. Provision had been made in the stereophonic equipment for 'spot' microphones to be used for the same purpose, the output of each such microphone being divided between the left- and right-hand channels through a 'panning' control.* With the introduction of these microphones, however, a fundamental difficulty became apparent. Whenever sound from a particular musical instrument is picked up at comparable levels, either on two 'spot' microphones, or on one 'spot' microphone and one of the main stereophonic microphones, the two microphones concerned form a spaced pair yielding independent directional information. The directional information derived from the spaced pair, which largely depends on interchannel time differences, conflicts, in general, with that derived from the main microphone pair, which depends on interchannel amplitude differences, and the overall effect is that the image of the musical instrument concerned wanders about according to the particular note being played. Again, if a soloist provided with a 'spot' microphone is artificially 'placed' by the panpot in a position different from that determined by the stereophonic microphone pair, adjustment of the spot channel fader during the performance causes the resultant image to wander between the two positions.

These and other anomalies can also occur when more than one stereophonic pair is used. In the course of experiments on a *Show Time* programme on one occasion, two stereophonic microphone pairs, provided for the orchestra and chorus respectively, both picked up the soloist, who happened to be between the two pairs, to the left of one and to the right of the other. The time differences involved were too great to allow a single resultant image to be formed, and the soloist appeared to be simultaneously in two different positions on the stage; this difficulty was finally circumvented by reversing the chorus microphone pair left to right, so as to bring the two images into approximate coincidence.

It would appear from the foregoing that, to avoid directional anomalies or wandering of images, additional microphones must be introduced with discretion and should be so placed as to avoid any one instrument being picked up by any two of them at comparable levels unless these levels are already very low. In addition, 'panning' of instruments into completely arbitrary positions should be avoided unless each such instrument can be isolated, for example, by screens, from the rest; it is better practice to ensure that the actual disposition of the sound sources across the studio conforms to the order in which they are to appear in the final presentation.

A difficult problem arose whenever a group of instruments rather than a single instrument had to be reinforced by a 'spot' microphone. As the image produced by a single microphone can have no width save that due to the finite resolution of the stereophonic system—in practice of the order of one-tenth of the width of the stage—the group appeared in one position. A subsidiary stereophonic microphone pair can, of course, be used for reinforcement of a group, provided that care is taken that the directional information obtained from this pair either predominates over, or at least does not conflict with, that produced by the main stereophonic pair. It frequently happens, however, that the local microphones used for reinforcement are exposed at the rear to other sounds which it is desired to exclude. With a single microphone, this situation is met by a cardioid directional characteristic, but in the case of a stereophonic pair of microphones, set at an angle to one another, there is no region which is 'dead' for both left and right channels. Again, it is frequently required to present the group in a position to left or right of centre; to this end, a row of images from the subsidiary stereophonic pair can be displaced from the centre to some extent by electrical attenuation in one channel or by using unequal directional patterns, but these expedients lead to deterioration of the stereophonic presentation. Turning the microphone pair to one side is more satisfactory in this respect but it may lead to the pickup of unwanted sounds. At the moment, the best compromise in such cases seems to be the use of a single microphone or, in the case of a large group, two single microphones, placed towards either end, the outputs being appropriately panned; this arrangement was adopted with the BBC Concert Orchestra and chorus in the recordings made on two occasions at the Camden Theatre, a former variety theatre normally used by the BBC for light entertainment broadcasts. If the distance between the microphones is such that the pickup from a given source can appear in both channels with comparable amplitude, the two act as a spaced pair and the positions of the images are not very sharply defined; if, however, the group consists of a row of similar voices or instruments, this effect is of no great consequence and a widely spaced microphone arrangement may thus be fairly satisfactory for large choirs. Another case where a widely spaced microphone pair may be necessary is in the transmission of a public performance of opera, where

* This type of control, originally described as a 'panoramic potentiometer' and now commonly known as a 'panpot', consists of a pair of ganged faders working in opposite directions; operation of the control increases the signal level in one channel while reducing it in the other.

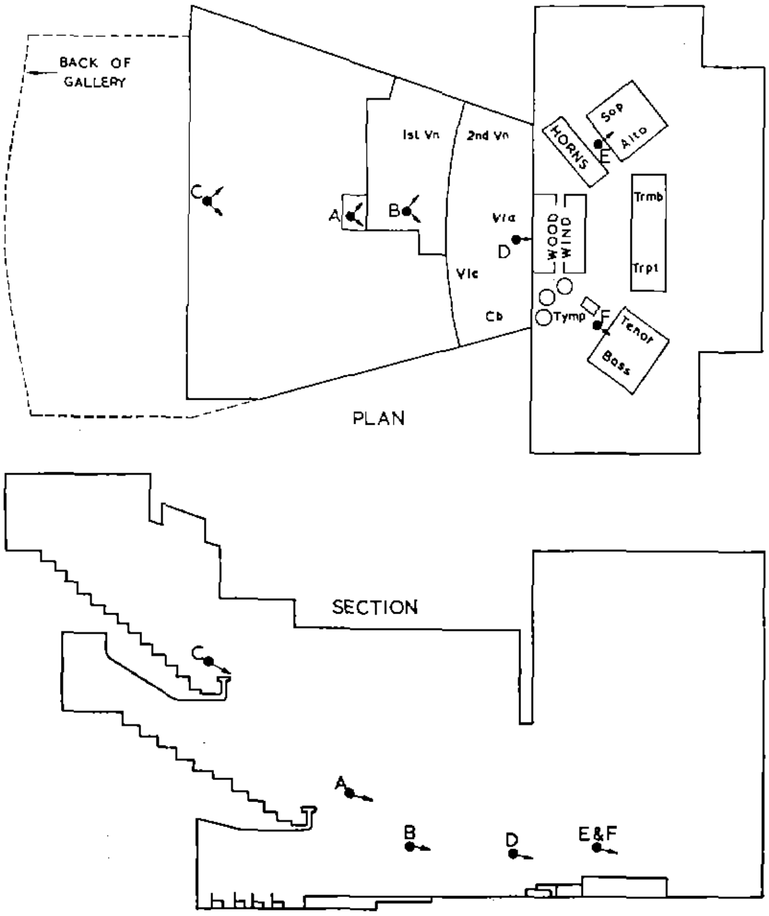

Fig. 1 — Studio layout for BBC Concert Orchestra, chorus, and vocalist, employing stereophonic microphone pairs, A, B, and C with single microphones D, E, and F

the presence of the prompter in the centre of the footlights makes it necessary to avoid sound pickup in this region. The arrangement is, however, unsatisfactory for soloists at the centre of the stage, where a movement of the performer's head can cause the reproduced image to jump from one side of the stage to the other.

It will be seen from the foregoing that, although the main stereophonic microphones in a multi-microphone system may operate as coincident pairs, any supplementary microphones tend to act as spaced pairs. It follows that interchannel time differences as well as amplitude differences appear and in practice there is a mixture of the two regimes.

The following account of an experiment carried out at the Camden Theatre, with the BBC Concert Orchestra, chorus, and solo singers, performing in a programme ranging from operatic selections to popular song arrangements, serves as an example of an effective multi-microphone technique.

The layout of the studio and the microphone positions used in this experiment are shown in Fig. 1. Because of the relative weakness of the string section of the orchestra, it was not possible to obtain an acceptable balance with the single stereophonic pair of cardioid microphones marked A in the figure. Rather than have recourse to a series of 'spot' microphones for the strings, a second cardioid pair B, with its axis in the same vertical plane as the first, was used to reinforce the front desk of strings. In some of the items, the lower strings, which were situated on the right-hand side* of the microphone pair, were found to require the addition of artificial reverberation, which was obtained by line from the echo room at Portland Place. To introduce the required reverberation without interfering with the reproduction of the higher strings on the left, the input to the echo room loudspeaker was taken only from the right-

* As seen when looking towards the performers. This is the normal convention adopted in stereophony, in which right and left refer to the viewpoint of the audience; it should be noted that in dramatic productions stage directions are given in the opposite sense.

hand microphone of the pair; this and other artifices employed in the application of artificial reverberation to stereophony are referred to in Section 5.5. A cardioid 'spot' microphone D was also provided to reinforce the woodwind.

It is common in monophonic programmes from this theatre to add reverberation by an additional microphone at the back of the balcony, where the direct sound pickup is negligible; a corresponding arrangement was adopted for the stereophonic presentation, using, instead of the single microphone, a third stereophonic pair C of figure-of-eight microphones in the balcony. The chorus, arranged in two groups behind the orchestra, presented some difficulty because it was not possible to obtain a proper balance between orchestra and chorus on the main microphones alone. For adequate reinforcement of the chorus without additional orchestral pickup, it was necessary to use a pair of cardioid 'spot' microphones, E and F, one for each group of singers; the limitations of this arrangement have been already pointed out. The solo singers were picked up on the second stereophonic microphone pair B.

2.4 *Polar Characteristics*

It was hoped at the start of the experiments to operate with microphones of fixed polar characteristic, making any necessary adjustments to the scale of width by adjustment of the angle between the microphones or by electrical cross-mixing of the resulting signals. It soon became apparent, however, that the wide variety of acoustic conditions encountered required corresponding changes in directional properties. For example, in the Liverpool Philharmonic Hall a peculiarity of local coloration due to mechanical vibration of the inner shell[5] made it impossible to employ microphones having cardioid characteristics, while in the recording of a string quartet in the Camden Theatre, figure-of-eight characteristics could not be employed because of sound reflected from the rear, which caused the images to change position with pitch.

Figure-of-eight characteristics, where they can be used, have the advantage that performers may be placed on either side of the stereophonic pair, bearing in mind, however, that sound sources which are diagonally opposite one another in the studio will be superimposed in the final presentation. In echo rooms, as already indicated, figure-of-eight characteristics were found satisfactory.

The angle between the two microphones of a coincident pair was in most cases 90°. At first sight it might be thought that this angle would need to be adjustable on every occasion, but it can readily be shown* that this necessity can be avoided by an adjustable polar characteristic of the usual form together with the facility for positive or negative cross-mixing between the left- and right-hand channels.

For a coincident microphone pair set at right angles, the angular displacement of a sound source required to move the reproduced image from one side of the stage to the other varies, in the absence of cross-mixing, between about 80° for a pair of microphones having figure-of-eight characteristics to about twice this angle for a pair of cardioids. With figure-of-eight characteristics, any sound arriving in one of the side quadrants, i.e. between 45° and 135° from the central axis, appears in the left and right channels in opposite polarity. For sound incident at the centre of these quadrants the left- and right-hand signals are equal as well as opposite in phase; the resulting sound is found to be unnatural and to many listeners positively unpleasant.† Reverberant sound arriving in an out-of-phase quadrant is usually inoffensive since it only forms part of the total reverberation and has only a small proportion of its energy at or near the middle of the quadrant. On the other hand, incidental noises—such as a passing car or a cough from an individual in the audience—reproduced in this way can be disturbing.

2.5 *The M–S System*

It remains to discuss briefly microphone arrangement 2.1 (*d*).

Consider a pair of identical coincident directional microphones inclined to left and right. If the outputs A and B‡ from these microphones are added, the resultant horizontal polar characteristic can be shown § to be that of a single microphone of suitable type facing forwards. If the outputs are subtracted, the resultant polar characteristic can be shown § to be a figure-of-eight facing sideways. Fig. 2 shows for example the resultant polar characteristics obtained by adding and subtracting the outputs of two identical coincident cardioid microphones with their axes at right angles. In Fig. 2 (*a*), the polar characteristics are plotted on a linear scale to illustrate the operations of addition and subtraction; in Fig. 2 (*b*), the same curves are reproduced on a decibel scale, and to facilitate comparisons between the shapes of the curves the maximum level has been drawn to the same radius in each case. It will be seen that the variations of $A+B$ and of $A-B$ with horizontal angle are such that each of these signals can be obtained directly from a single microphone of the appropriate type. A forward-facing microphone can be made to yield the $A+B$ signal, commonly designated M; at the same time a sideways-facing microphone having a figure-of-eight polar characteristic can be made to yield the $A-B$ signal commonly designated S. By subsequent addition and subtraction of the M and S signals, A and B can be recovered. This microphone arrangement is known as the M–S system.

Provided that the two microphones of a stereophonic system are coincident, it is in principle a matter of convenience whether the A and B signals are obtained directly from identical microphones inclined to left and right or derived from the corresponding M and S signals. It should be noted, however, that with the M–S arrangement the two microphones are of different kinds so that exact

* See Appendix IV.

† The deliberate use of reversed channels as a means for producing special effects will be referred to in the discussion of pseudo-stereophony.

‡ It is now customary to designate the two stereophonic signals as A and B rather than L and R, since the latter are unacceptable in the Latin languages.

§ See Appendix IV.

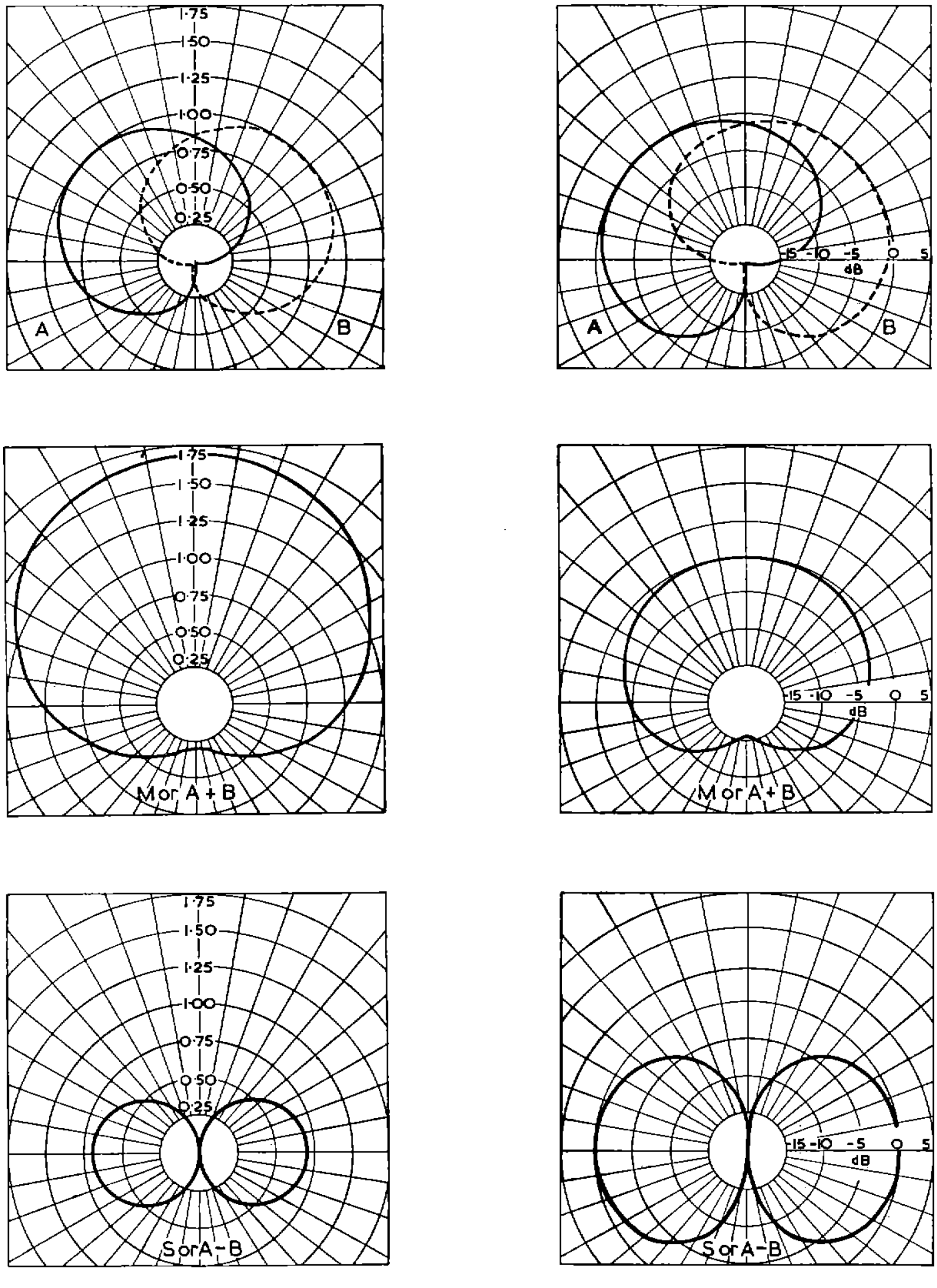

Fig. 2 — A, B, M, and S signals as a function of the angle of sound incidence for a pair of coincident cardioid microphones at right angles

(*a*) *Linear scale* (*b*) *Decibel scale*

matching of the response characteristics in both amplitude and phase may be more difficult to achieve than with left- and right-hand microphones of similar type. Moreover, because of the finite spacing between the two nominally coincident microphones, a corresponding small difference in time between the two outputs is unavoidable. It can be shown that time differences small enough to be negligible in the case of microphones producing the A and B signals directly can, in the M–S microphone arrangement, lead to appreciable cross-talk at high frequencies between the final A and B signals.

The letters M and S were originally used in the M–S system to denote respectively the outputs of the forward- and sideways-facing microphones; by an extension of the same idea they are now commonly employed as symbols for the sum and difference respectively of the left- and right-hand signals, regardless of the microphone system by which these are produced.

2.6 *Effect of Attenuating M or S Signals*

Consideration of the stereophonic signals in terms of the equivalent M and S microphones enables some of the properties of these signals to be more easily appreciated. It can readily be shown* that attenuation of the S signal reduces the scale of width so that the stereophonic images appear on a narrower front, while attenuation of the M signal produces the opposite effect.

It will be seen from Fig. 2 (*b*) that the horizontal angle covered by the equivalent single microphone giving the M signal is narrower than that covered by the corresponding left-right pair. Thus, the M signal contains in general a lower proportion of reverberation relative to direct sound than the complete stereophonic signal. On the other hand, the S signal, being derived in effect or in fact from a microphone with a figure-of-eight polar characteristic with one dead side towards the performers, carries a higher proportion of reverberation than that of the stereophonic transmission as a whole. If, therefore, the S signal is attenuated relatively to the M signal, e.g. for the purpose of narrowing the scale of width, the degree of reverberation in the stereophonic reproduction will be reduced, and vice versa. It is important to note that this effect is the opposite of that obtained by variation of the microphone distance, since in the latter case narrow-angle presentation is accompanied by increased reverberation. By combining the two methods of width adjustment, the reverberation as well as the width can be independently controlled.

3. Compatibility

3.1 *General*

It may be well at this point to re-state and qualify the definition of the term 'compatibility' in the sense in which it is used in this monograph. The essential idea of compatibility can be summarized by the following quotations from Engineering Monograph No. 29.

'A stereophonic system is said to be compatible when it can also yield a signal capable of giving satisfactory results on equipment designed for monophonic reception.'

'The programme reproduced on a monophonic receiver should so closely resemble a normal monophonic transmission that the degree of compatibility is, in practice, limited only by the nature of the programme material.'

Throughout the experiments, particular attention was paid to the requirements of compatibility. Wherever possible, an independent monophonic microphone system was set up and a normal monophonic version of the programme recorded simultaneously as a standard for comparison. With dramatic productions, it was impossible, on account of the movement of the actors, to make a simultaneous monophonic recording of the stereophonic production; in one case, however, a critical scene was re-enacted for comparison, using normal monophonic technique. For the purpose of the international study of microphone techniques by the E.B.U., a series of programme excerpts was produced in the form of stereophonic and monophonic recordings capable of being run synchronously, thus permitting direct comparisons to be made.

3.2 *Compatibility of Left- or Right-hand Signal Alone*

At the time that the investigation was commenced, interest was being expressed in the possibility of utilizing the left- or right-hand stereophonic signal alone to provide a monophonic programme, i.e. of achieving 'left–right compatibility'. In the earlier stereophonic systems, employing a pair of omnidirectional microphones spaced between 30 cm and 60 cm apart, left–right compatibility would at first sight appear to be automatically obtained, though even this only follows if the optimum microphone positions for stereophonic and monophonic reproduction are the same. However, the stereophonic effects obtainable with spaced omnidirectional microphones are poor by present-day standards and, as already indicated, current practice is to employ pairs of microphones which, by reason of their position or orientation, give prominence to sounds originating respectively on the left or right. In these circumstances, the reproduction from either channel taken by itself must necessarily be unbalanced; when listening, for example, to the left-hand channel alone, performers on the left-hand side of the stereophonic stage are heard in the foreground, while those on the right-hand side appear distant, a condition well exemplified in experiments with programme sources as diverse as the BBC Variety Orchestra and the choir of King's College Chapel, Cambridge.

It was necessary in the early stages of the work to investigate and demonstrate to the various interested parties the problem of achieving left–right compatibility; to this end a number of commercial stereophonic recordings as well as various items of recorded material produced in the course of the studio experiments were studied. It was concluded that while there is a certain amount of material—particularly symphonic music picked up with distant microphones—which would give a tolerably balanced reproduction on the left- or right-hand channel alone, there is nevertheless so much material which is not amenable to this treatment that it would be impossible to base a complete programme service on the assumption of left–right

* See Appendix III.

compatibility. This statement is, of course, based on the assumption that both stereophonic and monophonic balances are to be judged by current broadcasting standards. If it were decided as a matter of policy* to lower the standard of criticism, a considerably higher proportion of programme material could be said to exhibit left–right compatibility.

3.3 *Compatibility of Left- and Right-hand Signals Taken Together*

Most of the proposals for stereophonic transmission on a single radio-frequency channel do not demand left–right compatibility but assume that a satisfactory monophonic programme can be produced by adding the left- and right-hand signals A and B. Stereophonic programme material which meets this requirement may be said to exhibit '$A+B$ compatibility'.

A monophonic programme formed by the addition of the left- and right-hand stereophonic signals is clearly free from the one-sided effects referred to in the previous section and it is often assumed that in such a programme all the requirements of compatibility are automatically satisfied. While this assumption was found to be true in many cases, the studio experiments also revealed a number of potential sources of incompatibility which require to be taken into account, and these will now be discussed.

3.4 *Microphone Position*

As already pointed out in Section 2.6, the $A+B$, or M, signal carries in general a lower proportion of reverberation than that contained in the stereophonic transmission as a whole. Reproduction of the M signal on a monophonic receiver is therefore characterized by the relatively 'dry' quality commonly associated with sound picked up at short range. The effect of this result on compatibility is well illustrated by the case of two recordings of a string quartet made at the Camden Theatre. One recording, taken with a relatively close microphone position, was of the 'intimate' type, while the other, obtained with a more distant microphone, could be described as a concert-hall type of presentation. While both recordings were agreed by all concerned to be good examples of their kind, that taken with the close microphone, having already a low proportion of reverberant sound, gave excessively 'dry' quality on the M signal; for a compatible transmission only the more distant balance would therefore have been acceptable.

It should not, however, be concluded from the above that the optimum microphone positions for stereophony as such are necessarily more distant than for the corresponding monophonic transmission; indeed, as has already been remarked in Section 2.2, the reverse is sometimes the case. It would appear that the listener's impression of the relative prominence of two reproduced sounds depends on whether these emanate from the same point, as in monophonic reproduction, or are separated laterally, as is possible with stereophony. A similar situation arises when the direct and reverberant sounds from a single source are reproduced stereophonically, since the former is localized while the latter is distributed over a wide front. Some change in balance must therefore be expected when the various sounds on the stereophonic stage are superimposed in the monophonic version (though the direction in which the change takes place is not always the same). One instance of this effect was noted in the dramatic production *A Scent of Sarsaparilla* where the level of background effects considered appropriate for stereophony was rather too high for the monophonic presentation. A more striking example was provided in an item for solo singer, chorus, and orchestra, recorded with a multi-microphone arrangement during a broadcast of *Show Time* at the Camden Theatre. The programme was balanced by listening to the stereophonic presentation. On reproducing the M signal, however, the soloist was found to be too prominent relative to the orchestra while the chorus appeared to have receded into the background. In a case such as this an acceptable compromise can be effected and was in fact achieved in later experiments, but this process requires more facility for experiment and for changes in studio layout than is possible when sharing an existing monophonic transmission.

3.5 *Use of Difference Signal for Special Effects*

In nearly all transmission systems in which the monophonic programme is provided by the $A+B$ or M signal, the additional information required to build up the stereophonic sound picture is provided in the form of a difference signal $A-B$ or S. In the stereophonic receiver, the original A and B signals are reconstructed by taking $(M+S)/2$ and $(M-S)/2$, from which it will be seen that any signal transmitted on the S channel will be applied to the two loudspeakers in reverse polarity. Special 'pseudo-stereophonic' effects, some of which will be discussed later, may be introduced by signals transmitted in the S channel only, while some workers have even introduced artificial reverberation into this channel. It is therefore important to note that the S signal is not recognized or reproduced by a monophonic receiver and effects which are essential to the monophonic version of the programme must not be introduced by additions to this signal.

3.6 *Timing*

Although not strictly an engineering matter, it may be of interest to note a form of incompatibility connected with timing, which became evident during experimental dramatic productions. In a stereophonic presentation, sounds such as the ringing of a church bell, or footsteps unaccompanied by dialogue, can be allowed to continue for a period which in the monophonic version would be regarded as monotonous. After the final recording of the catacomb scene from *The Cask of Amontillado*, the actors were asked, for comparison, to play the excerpt again in the manner to which they had been accustomed in the past.

* Such a change of policy would have far-reaching effects upon monophonic microphone techniques; if, for example, the programmes picked up by directional microphones turned to the left or to the right were deemed, within the new terms of reference, to be equally well balanced, much of the expertise at present exercised by studio managers would clearly become superfluous.

It was at once noted that the 'normal' performance was being taken at an appreciably brisker pace than the stereophonic presentation. For the monophonic version of the scene the time taken was found to be 11 per cent shorter.

4. Studios and Listening Rooms

4.1 *Drama Studios*

The most serious limitation in the use of existing studios for stereophonic working became apparent in the features and drama experiments in Studio 6A in Broadcasting House, having 'live' and 'dead' halves which can be separated by curtains. The minimum working distance from the microphones was found to be about 1 m; at closer range, small involuntary movements by the performer produced relatively large unwanted movements of the reproduced image. The maximum working range, limited by the dimensions of the studio to some 10 m, was then insufficient to give adequate contrast between near and distant speech and it was therefore difficult to convey the impression of a character advancing or retreating over a long distance. In one case, something of the desired effect was achieved by dividing the studio into two by the curtains, working in the 'dead' half and setting up at the junction of the curtains a curved corridor of acoustic screens extending into the 'live' half, along which the actors could enter and leave the scene. It was abundantly clear, however, especially when crowd scenes were attempted, that much more manœuvring space was needed. A further difficulty was encountered when the prerecorded outdoor sound of footsteps ascending a cobbled street was added to studio dialogue. The incongruity between the two sets of acoustics, already a problem in monophony, was aggravated by the presence, in the outdoor recording, of clearly identifiable discrete echoes from nearby buildings, which had no counterpart in the studio. It is evident therefore that for stereophonic drama, a large studio, sufficiently dead to allow the building-up of realistic outdoor acoustic

Fig. 3 — Listening room at Kingswood

effects, is desirable; a television drama type of studio would probably be suitable.

4.2 *Music Studios*

In music, apart from existing defects of the studio—which were found to be reproduced with more than ordinary fidelity—the principal difficulty encountered in the introduction of stereophony was the tendency to anomalous directional effects. In Maida Vale 1, for example, the apparent position of the string bass was found to wander with pitch. The effect was later reproduced experimentally by replaying a recording of a double bass on a loudspeaker appropriately placed in the studio, and appeared to be associated with reflection from the side walls; the condition can be mitigated by having the belly of the instrument turned towards the microphone. With piano music, anomalous movements of the image are particularly difficult to avoid, the reproduced sound tending to spread over a much wider angle than that subtended by the instrument itself; the effect is apparently a function of the local reflecting surfaces in the studio. The last of the piano programmes in the present series was recorded in the Farringdon Hall—a large general-purpose music studio—and was free from gross anomalies of this kind, but the subject requires further study. Other examples of unwanted directional effects produced by the proximity of hard surfaces such as screens or tables were encountered in the course of drama experiments, and it is clear that careful attention needs to be paid to the paths followed by early reflections.

4.3 *Listening Rooms*

The acoustic requirements for a listening room for stereophonic monitoring require special attention. It must be emphasized that failure to standardize the acoustic conditions can lead to unsuspected inconsistencies of judgment; for example, a programme which was considered highly satisfactory when reproduced in the narrator's studio in the Camden Theatre was considered too narrow in stage layout when heard elsewhere. Again, the narrator's studio at the Farringdon Hall when used as a listening room was found to exhibit such strong short-path reflections that it was impossible to obtain a clearly localized image, and additional acoustic absorbent material had to be introduced as a temporary measure. Experiments in the listening room in the Research Department premises at Nightingale Square, Balham, showed that, to prevent the stereophonic reproduction from deteriorating at the rear listening positions, it is advantageous to place part of the acoustically absorbent surfaces between and on either side of the two loudspeakers. This principle was followed in the design of the Research Department listening room at Kingswood, Surrey, shown in Fig. 3; here the wall panels are wideband sound absorbers with impermeable facings.[6] The curtain is drawn during listening tests to conceal the loudspeakers, thus avoiding any psychological bias towards the idea of a 'hole in the middle'. It is not suggested, however, that such concealment is essential with trained observers.

The listening room described has a floor area $7 \cdot 1$ m $\times$ $4 \cdot 1$ m and is suitable for stereophonic reproduction with an audience of up to a maximum of ten persons. The preferred seating area in stereophonic listening is approximately triangular, and is formed in this case by four rows having respectively one, two, three, and four seats. If such a room were to be used as a studio control cubicle, however, the control desk would take up about half of the audience area, leaving accommodation for only five, so that the dimensions given would still not be unduly large. It is to be noted that in the layout of a stereophonic cubicle, the producer and the studio manager, who are concerned with the exact placing of the sound images, should sit on the line midway between the loudspeakers, and that in dramatic productions the gramophone operator also should be at least within the stereophonic listening zone.

Most studio cubicles are too small to allow proper stereophonic listening conditions for more than two or three observers. In some of the experimental productions in Studio 6A, Broadcasting House, this difficulty was circumvented by using the associated narrator's studio as a listening room for the performers, thus relieving the congestion in the operating area.

For some of the experiments in which it was not possible to find a suitable listening room, a mobile laboratory vehicle was employed; in this case the spacing of the loudspeakers was limited by the dimensions of the vehicle to $1 \cdot 7$ m; as a result, it was necessary to limit the number of observers to two, one seated and one standing, at about the same distance from the loudspeakers, in order that the stage should subtend a sufficient angle at the listening point.

5. Control Equipment

5.1 *General*

The special requirements for control and monitoring equipment in stereophony have been outlined in an earlier monograph.[1] These requirements arise in part from the necessity of handling two programme channels simultaneously and in part from the extra dimension of width which the stereophonic presentation provides. Thus, the positions of the various images on the stage may have to be adjusted electrically, and special effects peculiar to stereophony may be added.

The equipment for the early experiments consisted, apart from the microphones and loudspeakers, of a duplicate set of amplifiers, a special double programme meter, having two pointers moving over a common scale to indicate the levels of the left- and right-hand signals respectively, and a pair of ganged control faders. The necessity for some form of scale-of-width control soon became apparent and this was improvised by a crossmixing attenuator bridging the left- and right-hand channels. When experiments with the Revue and Variety Orchestras required a multi-microphone balance with artificial reverberation, a small control desk was constructed, comprising two stereophonic channels, a stereophonic echo channel, and

two channels for single microphones with panpots. As it was not always practicable to utilize existing amplifiers on studio premises, a separate amplifier rack was provided so that the equipment should be self-contained. To meet the requirements of features and drama, pseudo-stereophonic effects, to be described later, were subsequently improvised by adding external circuits, but it was impossible to incorporate all the technical features which operational experience showed to be necessary. As the apparatus at this stage was becoming increasingly complicated to assemble and adjust, it was decided to make a fresh start, and a new self-contained transportable set of equipment[1] was constructed. A detailed description of the equipment would be beyond the scope of the present monograph, but reference to particular features of the design will be made in the course of the following sections, in which the various requirements will be discussed.

5.2 *Preservation of Left–Right Balance*

Care is necessary in the design and operation of stereophonic equipment to avoid any unwanted difference in gain between the left- and right-hand channels, since this would cause all images in the central region of the stage to be displaced to one side or the other. Under good listening conditions, a standing unbalance of only 2 dB may be perceptible to a trained observer, while in the reproduction of familiar recordings in familiar surroundings, the limit may be as low as 1 dB. Sudden changes in the relative gain of the channels are even more noticeable and, if the two halves of a control fader are not accurately ganged, changes in attenuation are accompanied by jerking of the images from side to side. This effect is most noticeable at high attenuations, when the steps on a fader are relatively coarse, and the fact that the sound level is then low does not mitigate the trouble.

The degree of standing unbalance may be lessened by fitting faders with a detent action which does not allow the contact arm to be left between studs; alternatively (or in addition) the attenuation per stud, and hence the possible error when one attenuator reaches the next step before the other, may be made smaller. To reduce the effect of the cumulative ganging errors of channel, group, and main faders in cascade, one or more of these faders may be made to operate, not upon the left- and right-hand signals, but upon their sum and difference. In the latter case, the effect of errors in ganging is to produce a change in the scale of width and hence a sideways displacement of those images which are already near the sides of the stage; by combining the two methods of attenuation, the errors are distributed over the stage instead of being concentrated in one region. It is advisable, however, to avoid the use of amplifiers in the sum and difference channels, since these channels have to be accurately matched in respect of phase response[1] as well as of gain.

Balancing of the two loudspeakers used in stereophonic monitoring is carried out by applying identical signals to both and adjusting an associated trimming attenuator so that the image perceived by a central observer is central. This operation must be carried out using speech or other complex signals covering at least three or four octaves in the middle of the audio-frequency band; it has been found that because of residual differences in frequency response and the effects of room reflections—both of which can only be dealt with by averaging over a wide band—reliable subjective judgments of the position of stereophonic images cannot be made with a single frequency.

Normal production tolerances for broadcast quality microphones permit a difference in sensitivity of some 4 dB between any two nominally identical specimens. Unless some process of frequent testing and selection of microphones, such as is carried out in some commercial recording studios, is adopted, each microphone channel will therefore require a trimming attenuator which can be used to compensate any unbalance between left and right; any difference in gain between the corresponding microphone amplifiers can be taken up at the same time. The balancing operation can be conveniently carried out by temporarily turning the two microphones (assumed to be coincident) so that their axes are parallel and applying the difference between the left- and right-hand signals to a single loudspeaker. The trimming attenuator is then adjusted for minimum reproduced sound; accidental reversal of polarity is automatically disclosed by this test, since in such a case it would be impossible to obtain a minimum. As in the case of loudspeaker balancing, residual differences have also to be averaged, so that a wide-band signal, such as is produced by speech or music, is again necessary.

5.3 *Width Control*

Reference has already been made to the practice of cross-mixing between left- and right-hand channels as a means of controlling the scale of width, and to the fact that the same effect can be produced by attenuating the corresponding sum or difference signals. The relationship between the sum or difference attenuation and the cross-mix attenuation for the same scale of width, shown in Fig. 4, can be readily calculated* and it can be shown that attenuation of the difference signal or sum signal corresponds respectively to direct cross-mixing or negative cross-mixing (the latter being produced by reversing the polarity of the cross connection). It can also be shown* that direct cross-mixing produces a rise of a few decibels in the overall reproduced sound level whereas attenuation of the sum or difference signal has the opposite effect. This change in level depends on the degree of correlation between the left- and right-hand signals and hence on the nature of the programme, but except in cases of sudden changes in width introduced for dramatic effect, it can generally be neglected.

5.4 *Single Channel Inputs*

As already indicated, it is frequently necessary to supplement the pairs of microphones employed to present an overall stereophonic picture with a number of 'spot' microphones, the output of which is divided between the left and

* See Appendices II and III.

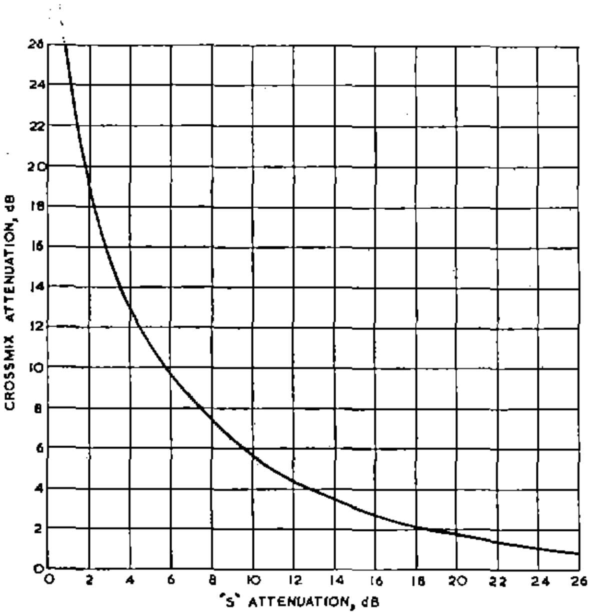

Fig. 4 — Relationship between cross-mix attenuation and 'S' attenuation to give the same scale of width

right channels in an arbitrary ratio. Experience shows that the number of such 'spot' channels required for simultaneous use in musical programmes is at least four, while in dramatic productions an even greater number is desirable to permit a number of different effects to be presented in rapid succession without recourse to repeated recording.

In the production of *Sherlock Holmes*—the first attempt at stereophonic drama—the Studio Manager found himself in difficulties on account of the number of controls to be manipulated simultaneously. To ease this situation, therefore, the present desk was provided with a foot-operated panning control actuated by a rocking pedal, the angular setting of the panning control being indicated by a centre-zero meter mounted on the control panel.

When the image has to be panned rapidly from one side of the stage to the other, there is a tendency for the listener momentarily to lose track of it. It has been found possible to counteract this effect by introducing a temporary increase in level of a few decibels at mid-stage. The required compensation can be produced by modifying the design of the panning attenuator, but in the equipment described it is brought about by a cam-operated fader mechanically coupled to the foot-operated panning control; the latter method possesses the advantage that other effects, such as the sound of a vehicle approaching from a distance on the left and receding into the distance on the right, can be produced by substituting a cam of appropriate profile.

5.5 *Artificial Reverberation*

In stereophonic as in monophonic sound reproduction, it is often desired to introduce artificial reverberation. In stereophony, however, two additional variables are introduced, since there are several ways of deriving the inputs to the artificial reverberation chain as well as several ways of introducing the output into the final presentation.

The various methods of obtaining an echo room input may be illustrated by reference to Fig. 2, which shows, for the case of a pair of cardioid microphones at right angles, the variation in the signals A, B, M, and S with angle of sound incidence. It will be seen that an input derived from the M signal will be nearly independent of the position of the image on the stage—the condition most frequently required in practice.

It may, however, be required upon occasion to apply more reverberation to sounds whose images appear on one or other side of the stage, and in the present control desk this can readily be arranged by taking the echo room input from the A or B signal alone. An example of such a requirement has already been given in Section 2.3 and other applications can be envisaged in dramatic productions. It should be noted that when deriving the echo room input in this way the added reverberation is not confined to sound originating in a well-defined left- or right-hand zone in the studio, but varies progressively with angle of incidence in accordance with the polar characteristic of the microphone.

A further alternative method of obtaining the echo room input is to utilize the S signal. In this case, the added reverberation is zero for a central image and increases as the image moves towards the extreme left or right. This device might be used in simulating the passage of a sound source approaching on one side and receding on the other; it could conveniently be employed in conjunction with a monophonic source controlled by a panpot.

The output of the echo room can be utilized in a number of ways. The normal function of artificial reverberation is to give an effect similar to that of natural reverberation in the studio. To this end, the echo room can be treated as a studio and provided with a pair of stereophonic microphones so that the reverberation picked up appears in the final presentation to come from all parts of the stage. For special purposes, for example in drama, it may be required to simulate the effect of reverberation originating at the left, right, or centre of the stage. These effects can be produced in the present control desk by feeding the combined output from the echo room microphones respectively to the left- or right-hand programme channel or to both equally.

To obviate the need for a pair of microphones in the echo room, it has been suggested that the artificial reverberation from a single microphone should be fed to the left- and right-hand channels in reversed polarity, i.e. should be treated as an S signal. This artifice will be referred to later in the discussion of pseudo-stereophony.

5.6 *Effects Reproduced on Studio Loudspeakers*

The common device of introducing effects played on loudspeakers in the studio is equally applicable to stereophony and was employed in several of the experimental dramatic productions. In one case, two loudspeakers carrying different effects were placed in different parts of the studio and produced images in corresponding parts of the

stage. In another instance, a pair of loudspeakers, placed on the extreme left and right of the working area in the studio, was fed from a common source through a panpot and it was found possible to form a single image which could be moved across the stage as required; in setting up a pair of loudspeakers for this purpose the relative gain and polarity of the two sides were adjusted, as in the case of monitoring loudspeakers, by listening at a point midway between them.

5.7 *Compatibility Check*

Assuming that the transmission system employed utilizes the sum of the left- and right-hand signals to provide a monophonic programme, it is necessary for the operator to be able, without interfering with transmission, to hear the sum signal reproduced on one loudspeaker and thus to check from time to time that the requirement of compatibility is being met; this facility is provided on the present control desk by a suitable switch. It is not always easy, however, for an operator who has become accustomed to hearing the stereophonic presentation to readjust himself instantly to monophonic standards; ideally, therefore, the monophonic version of the programme should be continuously monitored in a separate cubicle. Some continental workers have carried this idea further by proposing that all microphone mixing should be carried out by the 'monophonic' operator, leaving only the panning and scale-of-width adjustments under the control of the operator concerned with the stereophonic presentation. The advantages and disadvantages of the latter arrangement depend only on considerations of convenience and cost and it should be made clear that the fundamental problems of compatibility already discussed are unaffected by any such changes in instrumentation.

5.8 *Pseudo-stereophonic Effects*

Reference has been made in an earlier monograph[1] to the possibility of producing pseudo-stereophonic effects by splitting a monophonic signal between two channels through electrical networks yielding 'left-hand' and 'right-hand' outputs which differ in amplitude and phase by some arbitrary law. In one commercial application of this device, the high- and low-frequency components of this signal are made predominant in the left- and right-hand channels respectively; the intention here is to imitate the layout of an orchestra, with the high-pitched instruments on the left and the low-pitched instruments on the right.

Artifices of this kind, while originally intended as a substitute for stereophony, can be used in the production of stereophonic programmes to give special effects; in such cases, however, the usual requirement is for a uniform distribution of sound across the stage, independent of frequency. In the course of the first experiment in stereophonic drama, for example, it became necessary to spread the sounds of wind and rain, derived from monophonic effects discs, to form, as it were, a continuous backcloth to the scene; the same device was also used to 'delocalize' the voice of the narrator. The circuit employed to produce these effects became known among the programme staff as the 'spreader'.*

The spreading effects in the early experiments were obtained by dividing the incoming signal between the left- and right-hand channels and interposing in one of these channels a phase-shift network having a group delay of approximately 1 ms; the resulting displacement of the image was counteracted by the insertion of some 6 dB of attenuation in the other channel. The two channels were then cross-mixed through an attenuator of some 10 dB loss; this caused the ratio of the outgoing left- and right-hand signals to rise and fall alternately with increasing frequency, so that the various components of a complex sound were spread across the stage.

This relatively crude expedient was only partially successful, largely because of the rather short delay time of the available networks. The spread did not extend over the full stage width, and on speech the image, while blurred, was far from being delocalized; moreover, the quality of reproduction was adversely affected, especially in the case of the sum of the left- and right-hand signals. In designing the present studio equipment, it was found unnecessary to preserve constant difference in group delay between the two channels. Improved results were obtained with networks giving a differential phase-shift constant up to about 500 c/s, thereafter increasing rapidly with frequency. At the same time, the final left- and right-hand outputs were formed by taking the sum and difference of the direct and phase-shifted signals; with this arrangement a 'monophonic' listener receiving the combined output of the left- and right-hand channels hears only the direct signal. An analogous arrangement, in which the necessity for a delay network was avoided by the use of an auxiliary microphone spaced from the main microphone, was also adopted in one of the productions.

Reference has already been made in Section 2.4 of the effect of applying to the left- and right-hand channels equal signals with opposite polarity. For observers midway between the loudspeakers, the resulting sound image is diffused across the stage and it has at various times been suggested that this effect should be utilized as a form of pseudo-stereophony. The arrangement has, however, a number of disadvantages. The normal two to three metre spacing between loudspeakers is insufficient to prevent partial cancellation of sound at low frequencies. so that there is a loss of bass which becomes even more serious in cases where the full spacing is not possible. The sound heard by a central observer has an unpleasantly unnatural quality, and the spreading effect is more critical with lateral shift of the observer's position than with a normal stereophonic presentation of sound on a wide front; a relatively small movement to one side causes the sound to appear concentrated on one loudspeaker. In spite of these drawbacks, the device of reversing polarity has been used in some continental experiments as a means of introducing artificial

* It should, however, be noted that the term 'spreader' has been used by other writers[7] to describe the sum-and-difference type of width control, although this device can be used to narrow as well as widen the stereophonic presentation.

reverberation from a single microphone in the echo room. A serious objection arises here from the requirement of compatibility, since reverberation presented in opposite phase in the two channels cancels out in the sum signal; since, as already noted, the monophonic version of the programme provided by the sum signal is in general less reverberant than the stereophonic version, the loss of artificial reverberation is a step in the wrong direction.

Experience indicates that pseudo-stereophonic effects as an adjunct to normal stereophonic programmes should be applied with some caution, as the resulting sound always has an element of unnaturalness which can produce in some observers a feeling of strain after prolonged listening. In producing a continual background such as crowd noise, it is preferable to use several similar but not identical recordings panned so as to appear at a number of points —three will normally suffice—across the stage.

5.9 *Programme Metering*

Throughout the experiments, programme levels were observed and controlled with the aid of a double programme meter provided with two independent movements mounted coaxially with the two differently coloured pointers operating on a common scale. The two meter movements were actuated by a pair of standard peak[8] programme meter circuits fed with signals from the left- and right-hand channels respectively. It would have been possible to construct a circuit which would enable the greater of the two programme levels at any moment to be displayed on a single indicating instrument. For experimental purposes, however, the double programme meter was found to be of great practical value in disclosing the existence of abnormalities or fault conditions, and as a number of these instruments was readily available, the alternative arrangement has not so far been adopted. With the use of multiplex transmission the possibility of feeding the two programme meter circuits with the M and S signals instead of the A and B signals may eventually have to be considered, but this question is outside the scope of the present monograph.

6. Conclusions

The operational exercises described above have yielded valuable experience in the production of a wide variety of stereophonic programme material. It is manifest, from the experience gained, that some aspects of the subject still require further investigation. Stage productions in the presence of an audience still present a difficult problem because of restrictions on microphone placing, while the transmission of outdoor events, represented so far only by the Edinburgh Tattoos of 1958 and 1959, is adversely affected by wind, to which directional microphones, being necessarily responsive to air particle velocity, are especially subject. Many possible alternative microphone combinations remain to be explored and, in particular, a satisfactory method of using subsidiary microphones to place a small group of instruments in any desired part of the stage has yet to be devised.

The compatibility or otherwise of the desired monophonic signal depends very much on the nature of the programme. Assuming the normal standard of judgment at present applied to the monitoring of programmes, the left- or right-hand signal alone cannot safely be assumed to yield an acceptable programme; on the other hand, the sum of these two signals can nearly always be made to do so by taking various precautions and making some compromises in balance. To safeguard the interests of the 'monophonic' listener it is essential that the 'compatible' version of the programme should be monitored, at least during rehearsals.

While many of the existing BBC studios leave something to be desired for stereophonic musical programmes, acceptable results can generally be obtained, given sufficient rehearsal time for experiment. A much more difficult situation arises in stereophonic drama, where a greater manœuvring space is required than is normally available; a large, acoustically 'dead' area, such as available in a television studio, may be required.

The monitoring arrangements for stereophonic programmes admit of little compromise and there are few existing studio cubicles which are sufficiently spacious and free from obstructions to meet the requirements. To ensure good listening conditions for those directly concerned in the production it is necessary to limit the number of persons in the cubicle and it may be advantageous upon occasion to provide an additional listening room for the use of performers and other interested parties.

Stereophony raises a number of special problems in the preliminary setting-up adjustment of the cubicle equipment and in the various additional manual controls necessitated by the extra dimension presented. However, equipment has now been constructed which fulfils most of the known operational requirements and will serve as a basis for future designs. A significant by-product of the investigation has been the formation of a nucleus of engineers and programme staff who have practical experience of stereophonic programme production of typical broadcast material. It is considered that the work described in this monograph should serve as a useful basis in the planning of a stereophonic service for the future.

7. Acknowledgments

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8. References

1. Shorter, D. E. L., and Phillips, G. J. **A Summary of the Present Position of Stereophonic Broadcasting,** BBC Engineering Monograph, No. 29, April 1960.
2. Heegaard, F. **The Reproduction of Sound in Auditory Perspective and a Compatible Stereophonic System,** E.B.U. Review, No. 52, p. 2, December 1958.
3. Blumlein, A. D. **British Patent No. 394, 325.**
4. Shorter, D. E. L., and Harwood, H. D. **The Design of a Ribbon Type Pressure-gradient Microphone for Broadcast Purposes,** BBC Engineering Monograph No. 4, December 1955.
5. Somerville, T. **A Comparison of the Acoustics of the Philharmonic Hall, Liverpool, and the St Andrew's Grand Hall, Glasgow,** BBC Quarterly, Vol. 4, No. 1, April 1949.
6. Gilford, C. L. S., and Druce, N. C. H. **Wideband Sound Absorbers with Impermeable Facings,** paper read at Third I.C.A. Congress, Stuttgart, September 1959.
7. Clark, H. A. M., Dutton, G. F., and Vanderlyn, P. B. **The 'Stereosonic' Recording and Reproducing System,** Proceedings I.E.E., Paper No. 2332 R, Vol. 104, Part B, p. 417, September 1957.
8. BBC Engineering Training Manual, **Studio Engineering for Sound Broadcasting** (London, Iliffe & Sons Ltd, 1955). Ch. 8, pp. 162–8.
9. de Boer, K. **The Formation of Stereophonic Images,** Philips Technical Review, Vol. 8, p. 51, 1946.

APPENDIX I

LIST OF OPERATIONAL EXPERIMENTS

Date	*Place*	*Nature of Programme*
10. 1.58	Maida Vale 1	BBC Symphony Orchestra with solo piano
31. 1.58	Maida Vale 1	BBC Concert Orchestra
4. 2.58	Maida Vale 1	BBC Symphony Orchestra with solo violin
14. 3.58	Staff Training Department	Dramatic excerpt
25. 8.58	Edinburgh Castle	Military Tattoo
18. 9.58	Royal Albert Hall	BBC Symphony Orchestra with solo piano
19. 9.58	Royal Albert Hall	BBC Symphony Orchestra and Choral Society
24. 9.58	Aeolian 1	BBC Revue Orchestra with vocalist
25. 9.58	Aeolian 1	BBC Variety Orchestra
1.10.58 2.10.58	Broadcasting House, Studio 6A	Drama: *Sherlock Holmes*
17.10.58	Philharmonic Hall, Liverpool	Liverpool Philharmonic Orchestra
19.11.58	Maida Vale 1	Two-piano duets
19.11.58	Maida Vale 1	BBC Symphony Orchestra
20.11.58	Maida Vale 1	BBC Symphony Orchestra and Choral Society
26.11.58	Camden Theatre	BBC Concert Orchestra and Chorus and solo singers (*Show Time*)
24.12.58	King's College Chapel, Cambridge	Carol Festival
20. 1.59	Farringdon Hall	BBC Singers
28. 1.59	Hammersmith Town Hall	Philharmonia Orchestra and choirs
7. 2.59	Walthamstow Town Hall	BBC Symphony Orchestra
7. 2.59	Walthamstow Town Hall	BBC Symphony Orchestra (including item for wind bands and strings)
12. 3.59	Aeolian 1	Dance Band Section of BBC Variety Orchestra
12. 4.59	King's College Chapel, Cambridge	Organ recital
3. 6.59	Maida Vale 1	BBC Symphony Orchestra
12. 8.59	Maida Vale 1	Solo piano
12. 8.59	Maida Vale 1	New London String Quartet
22. 8.59	Edinburgh Castle	Military Tattoo
5.10.59 6.10.59 7.10.59 8.10.59 9.10.59 12.10.59 13.10.59 14.10.59 15.10.59 16.10.59	Broadcasting House, Studio 6A	Plays: *The Cask of Amontillado* *The Derby that was Different* *A Scent of Sarsaparilla*
17.11.59	Farringdon Hall	Solo piano
17.11.59	Farringdon Hall	BBC Men's Chorus
18.11.59	Camden Theatre	Pro Musica String Quartet
10.12.59	Maida Vale 1	BBC Choral Society
11.12.59	Maida Vale 1	BBC Symphony Orchestra
30.12.59	Camden Theatre	BBC Concert Orchestra, Chorus, and solo singers
21. 2.60	Camden Theatre	Orchestra, chorus, and soloist of Sadler's Wells Opera
24. 2.60	Camden Theatre	Southern Serenade (Latin American music)

Date	Place	Nature of Programme
21. 3.60 22. 3.60 23. 3.60 24. 3.60 25. 3.60 26. 3.60 28. 3.60 29. 3.60 30. 3.60 31. 3.60 1. 4.60	Broadcasting House, Studio 6A	Vocal duets with harpsichord and viols: 'Pastoral Dialogues' Dramatized poem: *Under Milk Wood* Poem with sound effects: *Panacousticon* Play: *The Bullet*
21. 5.60 25. 5.60	The Playhouse, Manchester	BBC Northern Dance Orchestra

APPENDIX II

ELECTRICAL CONTROL OF SCALE OF WIDTH BY CROSS-MIXING

Consider the circuit shown in Fig. 5, in which the left- and right-hand signals A and B, assumed to be of the same sign, are cross-mixed by connecting an attenuator between the two channels and adding such series and shunt resistances as are necessary to preserve constant impedance conditions. Provision is made for reversing the connections to one side of the attenuator, as shown dotted in the figure, to give negative cross-mixing.

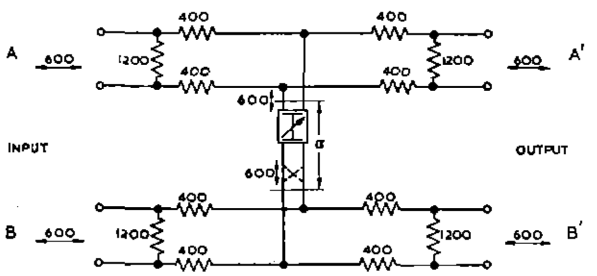

Fig. 5 — Typical cross-mixing control circuit

Let the fraction of the voltage in one channel fed to the other channel be α $(-1 \leqslant \alpha \leqslant 1)$. Then the two outgoing signals A' and B' may be written

$$A' = k(A + \alpha B)$$
$$B' = k(B + \alpha A)$$

where k is a constant representing the standing loss in the matching networks. Thus,

$$\frac{A'}{B'} = \frac{A + \alpha B}{B + \alpha A}.$$

In a stereophonic system operating with coincident microphones, the displacement of a reproduced image from the middle of the stage is determined by the ratio of the left- and right-hand signals; when this ratio is unity, the image remains central. Clearly, as α is increased from zero to unity, A'/B' increases or decreases steadily to unity, so that the scale of width is reduced; when $\alpha = 1$, i.e. with no attenuation, A' and B' become equal and all images are brought to the centre of the stage.

In the case of a stereophonic system employing spaced omnidirectional microphones the subjective effect of cross-mixing is the same as with coincident directional microphones, though the hearing mechanism concerned is different; the theory of operation under these conditions is discussed in the literature.[9]

If the connections to one side of the cross-mixing attenuator are reversed, negative cross-mixing takes place and the scale of width is increased; by this means a row of images initially occupying only the central region of the stage may be made to cover the full stage width. This process must not, however, be carried beyond the point at which some of the images have been displaced to the extreme left or right of the stage; any greater degree of negative cross-mixing will result in signals appearing in the A' and B' channels in opposite polarity. In the extreme case, when $\alpha = -1$, a signal arriving in the A or B channel alone produces A' and B' signals which are equal and opposite; at the same time, equal signals in the A and B channels cancel, so that no central images can appear.

The combined output power in the left- and right-hand channels is proportional to $(A')^2 + (B')^2$, i.e. to $(A + \alpha B)^2 + (B + \alpha A)^2$, and is therefore a function of α. In the extreme case of $\alpha = 1$, the total output power can be readily shown to be increased, relative to the value when $\alpha = 0$, by an amount which varies between 3 dB if A and B are equal in level but uncorrelated and 6 dB if $A = B$; the increase is clearly due to the appearance, in the output circuits, of power which would otherwise be dissipated in the cross-mixing attenuator. With complete negative cross-mixing, i.e. $\alpha = -1$, the total output power again rises by 3 dB if A and B are equal in level but uncorrelated, but vanishes if $A = B$.

APPENDIX III

ELECTRICAL CONTROL OF SCALE WIDTH BY ATTENUATION OF SUM OR DIFFERENCE SIGNAL

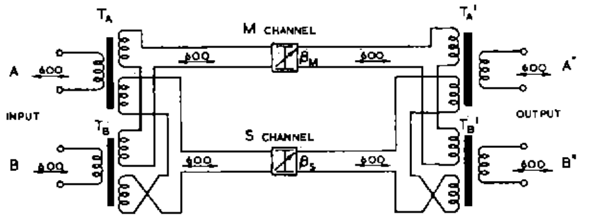

Fig. 6 — Typical sum and difference control circuit

Consider the circuit shown in Fig. 6, in which the incoming signals A and B are applied to transformers T_A and T_B, each having two independent secondary windings wound with $1/\sqrt{2}$ of the primary turns. By connecting the corresponding half secondaries of T_A and T_B in series in phase and in opposition respectively, sum and difference signals are obtained; the signal voltages in the sum and difference channels are respectively $(A+B)/\sqrt{2}$ or $M/\sqrt{2}$ and $(A-B)/\sqrt{2}$ or $S/\sqrt{2}$, the factor $1/\sqrt{2}$ signifying that the power in the A and B channels is equally divided between the M and S channels. The M and S channels are recombined, after attenuation, in transformers T_A' and T_B'—which are identical with T_A and T_B but with the functions of the primary and secondary windings reversed—to form the outgoing left- and right-hand signals A'' and B''.

Let β_M and β_S be the factors by which the voltages in the M and S channels are reduced by their respective attenuators. Then, if $\beta_S/\beta_M=\sigma$, the left- and right-hand output signals can be written

$$A''=\tfrac{1}{2}\{\beta_M(A+B)+\beta_S(A-B)\}=\tfrac{1}{2}\beta_M.\{(A+B)+\sigma(A-B)\}$$

$$B''=\tfrac{1}{2}\{\beta_M(A+B)-\beta_S(A-B)\}=\tfrac{1}{2}\beta_M.\{(A+B)-\sigma(A-B)\}$$

Clearly, if β_M and β_S are reduced in the same proportion, the ratio A''/B'' is unchanged. If, however, the attenuation in the difference channel is progressively increased over that in the sum channel, so that σ becomes less than unity, A''/B'' approaches unity, i.e. the scale of width is reduced; this result is similar to that already given in Appendix II.

The relationship between the degree of cross-mixing and the difference attenuation required to produce the same scale of width can be deduced by considering the ratio of the outgoing left- and right-hand signals.

$$\frac{A''}{B''}=\frac{\tfrac{1}{2}\beta_M\{(A+B)+\sigma(A-B)\}}{\tfrac{1}{2}\beta_M\{(A+B)-\sigma(A-B)\}}=\frac{A(1+\sigma)+B(1-\sigma)}{A(1-\sigma)+B(1+\sigma)}$$

$$=\frac{A+B\left(\frac{1-\sigma}{1+\sigma}\right)}{B+A\left(\frac{1-\sigma}{1+\sigma}\right)}$$

Comparing this result with the expression for A'/B' in Appendix II, it will be seen that as far as the scale of width is concerned, the two methods of control give the same result if

$$\alpha=\frac{1-\sigma}{1+\sigma}$$

The relationship between α and β_S with $\beta_M=1$ is plotted in Fig. 4 to a decibel scale.

It will be noted that if the attenuation of the sum signal is increased above that of the difference signal, thus making σ greater than unity, the corresponding value of α is negative, i.e. the scale of width is expanded.

The combined output power in the left-hand and right-hand channels with difference attenuation is proportional to $(A'')^2+(B'')^2$, i.e. to

$$\{\beta_M(A+B)+\beta_S(A-B)\}^2+\{\beta_M(A+B)-\beta_S(A-B)\}^2$$

In the extreme case of $\beta_M=1$, $\beta_S=0$—equivalent, in terms of scale of width, to complete crossmixing—the total power can be readily shown to be decreased, relative to that when $\sigma=1$, by an amount which varies between 3 dB if A and B are equal in level but uncorrelated and 6 dB if $A=B$; the decrease in output is clearly due to the dissipation in the difference attenuator. If the sum instead of the difference signal is attenuated, the total output power is likewise decreased; if the sum signal is completely removed, the power loss is again 3 dB if A and B are equal in level but uncorrelated, but if $A=B$ the output vanishes.

APPENDIX IV

EFFECT OF VARYING THE ANGLE BETWEEN TWO COINCIDENT MICROPHONES USED FOR STEREOPHONY

Consider the response of a pair of identical coincident microphones, each having a polar diagram of the usual form,* to sound from a source P, which is at such a distance and of such an intensity as to produce unity response when the sound is incident along the microphone axis. The two microphones then yield respectively signals A and B, which can be written in the form

$$A \text{ (or } B) = \frac{1}{1+m}\{1+m \cos\phi\}$$

where ϕ is the angle of sound incidence, taken relative to the axis of the microphone concerned and m is a quantity which can be adjusted to give the required directional characteristic.

Now let the two microphones be turned, in the horizontal plane, so that their axes lie at the same angle ψ to left and right of the central axis of the system, as shown in Fig. 7. Let the angle of sound incidence, taken relative to the central axis of the system, be θ. Then the signals from the two microphones become

$$A = \frac{1}{1+m}\{1+m \cos(\psi-\theta)\}$$

$$B = \frac{1}{1+m}\{1+m \cos(\psi+\theta)\}$$

The sum and difference signals can then be written

$$M = A+B = \frac{2}{1+m}\{1+m \cos\psi \cos\theta\}$$

and $$S = A-B = \frac{2}{1+m} \cdot m \sin\psi \sin\theta$$

Now M, as a function of θ, clearly has the general form referred to earlier, with its maximum at $\theta=0$, while S represents a figure-of-eight with its maximum at $\theta=90°$, i.e. with its axis at right angles to the central axis of the system.

The position of an image on the stage depends only on the corresponding value of A/B, which in turn is determined by M/S; the latter may be written

$$\frac{M}{S} = \frac{1+m \cos\psi \cos\theta}{m \sin\psi \sin\theta}$$

Consider now the effect of altering the value of M/S by attenuating M or S; for simplicity, this operation will be represented by substituting for S a quantity $S'=\sigma S$, where $\sigma=\beta_S/\beta_M$ as in Appendix III, and may be greater or less than unity. Then the new ratio of the sum and difference signals will be

$$\frac{M}{S'} = \frac{1+m \cos\psi \cos\theta}{m\sigma \sin\psi \sin\theta}$$

If now a change is made in the angle ψ, the numerator of the above fraction can always be restored to its original value by altering m to keep $m \cos\psi$ constant; given the new value of ψ and of m, the denominator can also be restored to its original value, by so altering σ that $m\sigma \sin\psi$ remains constant. Thus, given the facility for varying m and σ, the effect of any change in ψ can be nullified, i.e. all the available conditions can be achieved, for any value of ψ between 0° and 90°. Since, however, S tends to zero as ψ tends to zero, it is not practicable to operate with very small values of ψ. Similarly, it is not practicable to operate with values of ψ closely approaching 90° while using a large value of m to restore the original M/S ratio, for in this case the M signal would be very small. A workable arrangement can, however, be obtained with $\psi=90°$ by using a pair of cardioid microphones, but here the range of variation in the system is restricted to the relation

$$\frac{M}{S'} = \frac{1}{m\sigma \sin\theta}$$

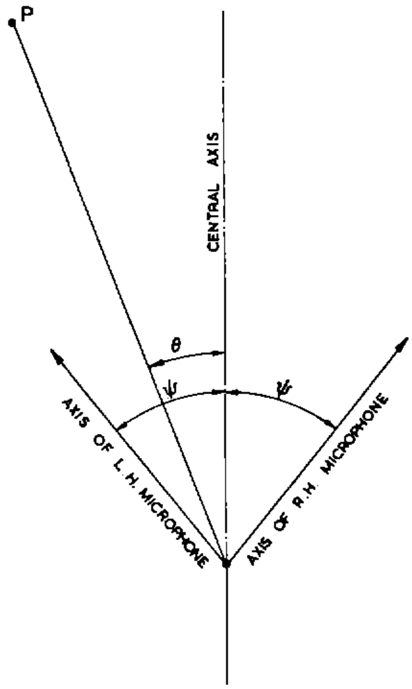

Fig. 7 — Orientation of coincident microphone pair relative to sound source

* The general equation is $A=p \cos\chi+q$, where the output voltage A from the microphone placed with its axis at an angle χ to the direction of sound propagation may be positive or negative. In drawing the polar diagram of a microphone, however, it is customary to plot the magnitude of A, regardless of sign, against χ.

SUMMARIES OF SOME RECENT BBC PATENT APPLICATIONS

PAT. APP. NO. 41605/60

IMPROVEMENTS RELATING TO TEMPERATURE-CONTROL MEANS

Inventor: V. G. GWYNN

The statement of invention reads:

According to the present invention there is provided apparatus for controlling the temperature of a region, the apparatus comprising a temperature-sensitive resistance element to be disposed in the said region, this element forming one arm of a D.C. bridge circuit, terminals for the application of a potential difference across one diagonal of the bridge circuit, a D.C. amplifier having its input connected across the other diagonal of the bridge circuit, and a resistive heating element to be disposed in a position to supply heat to the said region and connected in the output of the amplifier, a variation in resistance of the temperature-sensitive resistance element varying the degree of unbalance of the bridge circuit, and the resulting change of voltage at the input of the amplifier producing a change in the current in the heating element in such a sense as to tend to maintain the temperature of the said region constant.

PAT. APP. NO. 41856/60

IMPROVEMENTS RELATING TO THE MEASUREMENT OF RANDOM NOISE IN ELECTRICAL SIGNALS

Inventors: J. E. HOLDER and L. E. WEAVER

The statement of invention reads:

According to the present invention there is provided apparatus suitable for measuring the power of random noise superimposed upon an input signal consisting of synchronizing pulses separated by intervals during which the voltage does not change, the apparatus comprising a clamp circuit arranged to clamp at a fixed predetermined value the signal voltage occurring at predetermined times, gating means arranged to sample the clamped signal by means of gating pulses occurring at predetermined times fixedly related to the first-mentioned predetermined times, and means for applying the output of the gating means through a high-pass or band-pass filter to a power measuring device, the gating pulses being substantially free of frequency components within the band of frequencies passed by the filter.

PAT. APP. NO. 42689/60

IMPROVEMENTS RELATING TO THE MEASUREMENT OF RANDOM NOISE IN ELECTRICAL SIGNALS

Inventors: J. E. HOLDER and L. E. WEAVER

The statement of invention reads:

According to the present invention there is provided apparatus for measuring the power of random noise in a signal including synchronizing signals having random noise superimposed thereon, the apparatus comprising means for generating at least two carrier oscillations having frequencies which are separated by a substantial multiple of the line synchronizing frequency and which in use, are equal or substantially equal to integral multiples of the line frequency, means for mixing these carrier oscillations with the signal and for selecting from the result of the mixing bands of low frequency components corresponding to the carrier frequencies modulated by the noise at frequencies substantially midway between adjacent harmonics of the line frequency and means for measuring the power in the said bands.

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